Trajectory-based gait generation for Autonomous Humanoid GeNUS with Omni Vision

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Abstract

This paper describes the mechanical and electronic specifications, and the software implementation of the humanoid robot, GeNUS that has been developed to play soccer autonomously and to participate in the Hurosot event of FIRA Cup 2007. In addition to its 22 Degree of Freedom (DOF), the incorporation of sensors such as tilt sensor, vision sensor and digital compass enables GeNUS to react promptly and effectively to the unpredictable environment and to communicate among fellow robots.

1 Introduction

The aim to develop a team of fully autonomous humanoid to challenge and win the human world champion team in soccer by 2005 is a target by humanoid researchers in the world. Using the soccer game as a research platform, it helps to stimulate creative and innovative ideas that can be applied to AI and robotics research.

Many researches focusing on the integration of various disciplines such as autonomous agent, robotics and sensor-fusion [1] – [3] in a humanoid, aim to develop a humanoid that can behave and react in a human-like manner in a soccer playing environment. In another words, the research community is trying to develop a humanoid that can match a soccer player in terms of skill level.

In addition, in any team event such as soccer, teamwork is an important factor in winning games. Players have to communicate effectively with one another in order to execute accurate passing and implement various attacking and defending strategies. Therefore it is important to integrate an effective communication system to enhance coordination between humanoids of the same team. Once communication has been established, strategies and formations can be incorporated into the humanoid team. This is highly related to multi-agent systems [4].

GeNUS has been recently developed by NUS for Kid-size humanoid league for FIRA Cup 2007.With 22 DOF, GeNUS is able to closely simulate the locomotion of a human. The fusion of sensors provides valuable information about the environment to 2 Digital Signal Processors (DSP). Based on the collected information, the DSPs then determine the appropriate actions to be taken. Besides being aimed at performing efficiently in a soccer playing environment, it also serves as a platform for various research purposes.

In this paper, the incorporation and the integration of the modules in the humanoid robots are presented. The mechanical specifications of the GeNUS and the hardware specifications of the components are described in Sections 2 and 3 respectively. In Section 4, the software implementation of the humanoid robot system is discussed.

2 Mechanical Specification

To closely simulate the locomotion of a human, GeNUS has a total of 22 DOF. It has 6 on each leg, 3 at the hip, 1 at the knee and 2 at the ankle (Fig. 1). The actuators in the upper body provide the extra 10 DOF needed for stability, head movement, and recovering from fall.

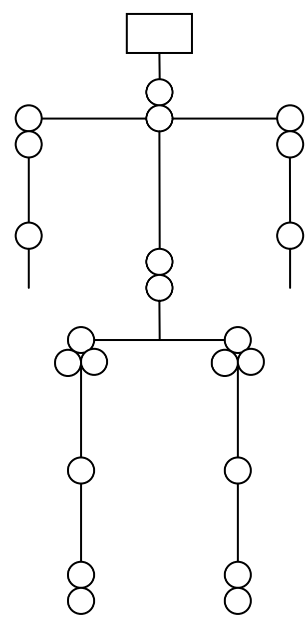

Figure 1: Mechanical Design of GeNUS

3 Electronics Specification

GeNUS, encompasses 22 actuators, 2 DSPs for decision making, a tilt sensor and a vision sensor for sensing.

3.1 Actuators

The actuators mounted are servos from HiTec [5]. The actuators for the head uses smaller servos in size in comparison with those mounted on the legs. The specifications of the servos are shown in Table 1.

Table 1. Specifications of Servos

Model	Size[mm x mm x mm]	Torque[kg-cm]	Speed[sec/60°]
HS-5245MG	32.4 x 16.8 x 30.8	5.5	0.15
HS-5945MG	39.4 x 20.0 x 37.8	13.0	0.13
HSR-5995TG	40.0 x 20.0 x 37.0	24.0	0.15

3.2 Digital Signal Processor

GeNUS has an on board processor that is responsible for controlling the sensors and actuators, and determining the course of action. The digital signal processor, developed by New Micros, Inc. [6], supports parallel processing. The processors make use of Virtually Parallel Machine Architecture (VPMA) [7], which allows independent machines to be constructed and run in a virtually parallel fashion. This allows efficient integration of all sensors to the processors.

3.3 Tilt Sensor

Positioned within the body of GeNUS, the tilt sensor, developed by Crossbow Technology, Inc. [4] is capable of measuring the tilt angles in 2 axes, the frontal plane and sagittal plane. The sensor has a range of $\pm 75^{o}$ both along the frontal and sagittal planes. This allows GeNUS to predict the stability of its motion

3.4 Vision Sensor

Visual information is obtained from a vision sensor mounted on the head. The vision sensor CMUcam2 [8] acts as a color sensor and provides the coordinates of the centre of an object that is being tracked.

Instead of using the conventional pan and tilt method for color scanning, GeNUS employs omni-vision which widens the color detection range. The vision sensor is positioned facing upwards and a spherical mirror is attached above. The spherical mirror reflects the image of a wide area to the visual sensor which enables it to capture a wider detection range. Employing the omni-vision allows GeNUS to find the ball quickly during a game play.

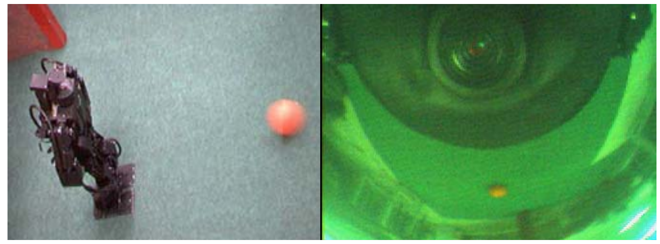

Figure 2: Image Acquired from Omni Vision

4 Electronics Specification

Utilizing the parallel processing feature offered by the digital signal processors, VPMA programming paradigm is used. This facilitates the integration of the sensors and the processors, providing GeNUS with real-time decision making and control.

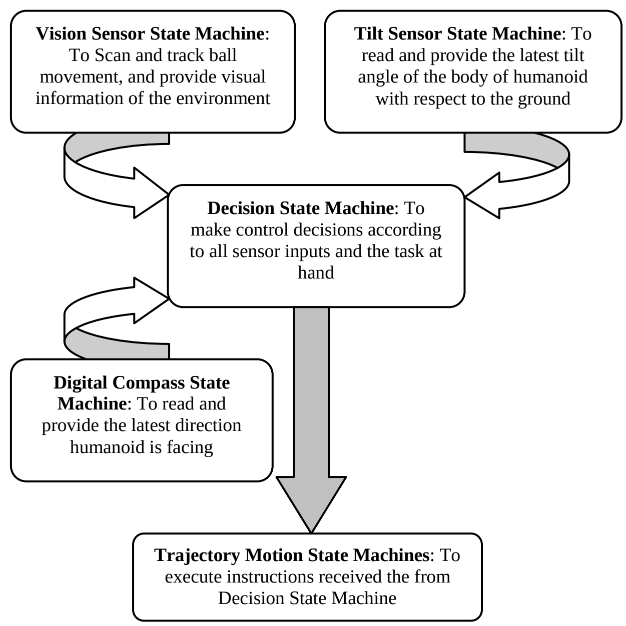

Figure 3: Overall Control System

In VPMA, a state machine is build to control each sensor on board and it is responsible for receiving and storing information from its assigned sensor. This form of architecture allows the high level control to access information from all sensors at any point in time and it also relieves the burden of requesting information from the sensors. In addition, this allows the high level control processor to model the environment more accurately and to mainly focus at performing certain task without worrying about organizing the activation sequence of the sensors.

The processor also stores various trajectory motions as state machines and activates appropriate machines as required. Fig. 3 illustrates the overall organization of the control system.

4.1 Trajectory Based Control

Trajectory-based control of the humanoid relates to the controls of the actuators based on pre-defined data and thus producing the required motion. Servos are not ideal actuators and thus control effort needs to be implemented to improve the performance of these servos as joint actuators.

4.1.1. Open Loop Control

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The servos used in GeNUS do not provide any feedback to the DSP, hence it can be considered as an open loop system. Pertaining to its own, each servo is a closed loop system. The assumption made on the servos is that the servos will always reach the position set eventually. However, this assumption in practice is not held true at all times. This assumption holds only if:

- The servos are operated within the technical specifications
- The servos are not mechanically constrained
- The servos are not overdriven.

Trajectory planning is employed to ensure that the assumptions made holds. By controlling the motion of the servos, operation of the servos can be more precisely controlled. Therefore, trajectory-based control effort is implemented.

4.1.2. Trajectory Generation

Trajectory-based control has the advantage of controlling the velocity and acceleration in which the actuators move. By such control, better and smoother gait motion can be produced. Trajectory planning can be done in several ways and three most common and simple path planning approaches are explored and examined.

Linear Trajectory: Linear path planning is the simplest and easiest method of path planning. Its advantage comes from the ease of implementation in term of concepts and programming. The movements of the actuators are incremented or decremented linearly when required. The implementation is done by considering the error between the desired starting and ending servo positions. This error is divided by the time required for the servos to move from the starting to the ending position. In theory, this method of path planning is not recommended as it would mean infinite acceleration and deceleration upon the start and end of the motion which are impossible. However, in practice, this method of trajectory works if the actuators can accelerate or decelerate rapidly. However, a major drawback of this method is that the acceleration and deceleration cannot be effectively controlled and estimated.

Linear Trajectory with Parabolic Blends: This is an extension method to the linear path planning method with the introduction of parabolic blends at the start and end of the motion such that there is finite acceleration and deceleration. However, experimental implementation result yield from this second order polynomial path planning did not show any improvement in the performance of the motion.

Cubic Polynomial Trajectory Planning: Joint positions are expressed as third-order polynomial of time as shown in (1).

$$\theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 \tag{1}$$

The coefficients are given as follows:

$$a_0 = \theta_0$$

$$a_1 = \dot{\theta}_0$$

$$a_2 = \frac{3}{t^2 f}(\theta_f - \theta_0) - \frac{1}{t_f}\dot{\theta}_f - \frac{2}{t_f}\dot{\theta}_0$$

$$a_3 = \frac{-2}{t^3 f}(\theta_f - \theta_0) + \frac{1}{t_f^2}(\dot{\theta}_f + \dot{\theta}_0) \tag{2}$$

where t_f denotes the duration time of motion,

θ_0 denotes the joint actuator initial position

θ_f denotes the joint actuator final position

$\dot{\theta}_0$ denotes the joint actuator initial velocity,

$\dot{\theta}_f$ denotes the joint actuator final velocity

The cubic polynomial path planning method is implemented which resulted in smoother motion. Fig.4

shows the PWM duty cycle trajectories generated by the cubic polynomial equations for the six actuators in a single leg of the humanoid.

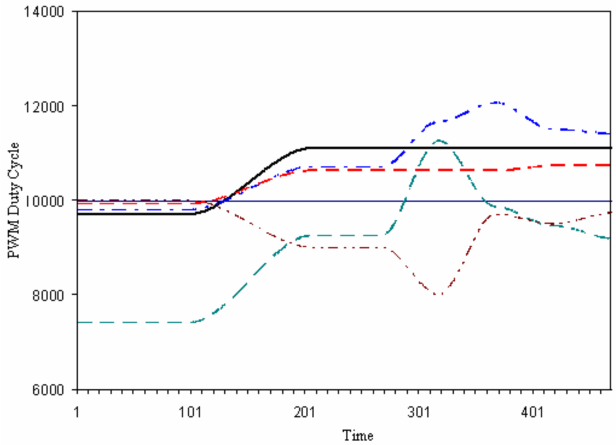

Figure 4: Trajectories For A Single Robot Leg

From the Fig.4, gradual changes are observed in the position movements of the servos when nearing the end or deviating from the start position. These gradual changes are the main facilitation of the smoother motion produced and observed physically. In addition, the cubic polynomial equations are capable of generating gait motions with non-trivial initial and final velocities to obtain smooth and continuous motions.

5 Conclusion

In this paper, we have presented the overview of GeNUS humanoid which is capable of playing soccer autonomously and reacting promptly to the soccer playing environment. The research done in this soccer arena also serves as a basis for other related research fields.

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